ITS Control and Surveillance Devices location modeling to Improve Safety

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ABSTRACT. Traffic safety in rural area can be considered as an important source of concern among the many countries. Nowadays, transportation professionals widely use intelligent transportation systems (ITS) to address safety problems. However, in comparison of metropolitan applications, the rural ITS applications still are not well defined. This paper provides a comprehensive survey on the all available ITS safety solutions in the rural highways. In addition, the study is mainly focused on the infrastructure-based control and surveillance ITS technology such as Crash Prevention and Safety, Road Weather Management and other applications that directly related to the reduction of frequency and severity of accidents.

The main objective of the paper is to develop the ITS control and surveillance devices locating model to improve safety on rural roads. In this research the updated ITS benefits and costs databases are used, and then the Integer linear programming is utilized as an optimization technique to choose the most suitable set of ITS devises.
Finally to demonstrate the effectiveness of the proposed methodology, a computational analysis was performed on a segment of rural highway in Iran is introduced.

INTRODUCTION

Safe movement is one of the most important goals of the road transportation, and is still a challenge all over the world. Every year crashes kill or injure thousands of people. This condition is really severed in Iran too, and its growing rates were more than ten percent in

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recent years. Nowadays, intelligent transportation systems introduce very useful applications to improve safety.

In the ITS application areas, almost safety is one of the goals, but in some of them it is the main and prime goal. All of the ITS applications can be classified and separated in three areas: 1) infrastructure-based 2) vehicle-based, 3) cooperative ITS, Mckeever, B. (1998). But approximately no vehicles use intelligent in-vehicle tools in Iran, therefore use of infrastructure base system are more applicable and practicable.
In addition in Iran the main portion of fatal crashes have been accrued in rural roads
Base on all of these reasons the goal of this study have been considered in usage of ITS infrastructure base applications in rural roads.

The goal of this investigation is to find the best places for installing the utilities and to find the priority of them. Until now locating intelligent utilities mostly has been based on engineering judgment and qualification. And the best status is not clear perfectly. The exact methodology must be based on IT systems and their effectiveness, while optimum solution should derive from exact mathematical optimization method, what is aimed in this paper.

In various studies on some ITS applications like AVL and CMS, the objective function was minimizing delay or travel time or maximizing network coverage, and safety in all of them wasn't considered or considered as the secondary objective with low priority. For instance, Lu and etc (2006) tried to locate these devices by maximizing coverage of network. Sherali , and etc. (2002) attempted to locate AVI readers by a combination model of linear integer programming.

In a study that had been done under the sponsorship of the road and transportation ministry of Iran in 2005, speed control cameras locating has been concerned. This study, for improving enforcement, tried to max the number of vehicles that have been controlled by speed cameras, Andishe Gostaresh consultant, (2005).

This paper tries to notice all applications of ITS, that they have some potential benefits in safety. For classification of all ITS applications areas and determination of their rural usages and their details, “state wide/rural ITS 2004”, which have been prepared for ITS JPO U.S.DOT, have been considered.

Comprehensive integrated data bank as like as ITS benefit site of the FHWA is one of the spacious sources to access accomplished evaluation projects through the United States and across the world, this integrated data bank has not been presented clear quantity for lots of ITS effectiveness yet. This paper utilizes two sources for assessment of the systems benefits. The first one is a survey which was prepared by Maccubbin R. (2003), and the second one is the benefit-cost report that was prepared by Maccubbin R. and etc. (2005), for ITS Joint Program office of U.S.DOT.

METHODOLOGY AND MODEL

Three factors contribute to road traffic accident; human, road environment, and vehicle factors. This classification presents a useful framework, for relating crashes to ITS applications because the proper ITS solution would differ, due to the cause of the crashes. This task had been done by Mccormack and Leg (1999) that summary of their finding in Table 7 of appendix is presented.

ITS devices choice

Rural area is our target area, so the ITS applications should be classified in this area; however, this area has some similar applications with ITS applications in metropolitan areas. On the other hand, according to last assumptions, only infrastructure-based systems are planned in this paper. Intelligent infrastructure in rural area can be categorized to:

- Crash prevention and safety
- Emergency services
- Travel and tourism
- Traffic management
- Transit and mobility
- Operation and maintenance
- Weather

Due to mention rural ITS application areas, and their different systems, proper systems should be elected. The criteria and conditions that were applied in this paper for system election, to use in ITS devices location modeling in the road sides, are including:

- They should be apart of ITS infrastructure systems; in fact, they do not need in-vehicle facilities.
- Their operation district should be in rural areas.
- They should be installed in a constant spot in the roadside and should be immovable, and also should be used in a long period of time.
- They should be improving safety by preventing crashes (post crash and incident management aren't objects of this paper).
- Prime and main goal of their implementation should be safety.
- They do not require high an expensive traffic control center

Table 1 has been used to control above mentioned criteria on application areas and their systems.

Only the systems satisfying all criteria (as marked on Table 1) are chosen and used in this study .These system are shown in table 2 .

Benefits and costs

The thirteen systems chosen in the previous section belong to the most common ITS applications in rural safety. In this section, evaluation indexes for systems' comparison will be determined.

Table 1. Control of the criteria for selection of proper systems

Criteria for electing systems	Application areas																										
	Crash prevention & safety								Traveler information					Road weather management				Traffic management			Intelligent vehicle			Commercial vehicle operation	Transit management	Emergency	Roadway operation & maintenance
	Ramp rollover warning	Curve speed warning	Downhill speed warning	Highway-rail crossing system	Pedestrian safety warning	Bicycle warning system	Animal warning system	Intersection collision warning	Internet/wireless	Portable DMS	Stationary DMS	TV/Radio	Telephone	Pavement condition information	VSL	Highway advisory radio	Internet/wireless/ phone	Automatic enforcement	Lane use/closure	Incident management	Collision avoidance system	Driver assistance system	Collision notification system	Related system	Related system	Related system	Fixed anti icing system
ITS infrastructure systems	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•								•
rural areas application	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
installing in a constant spot	•	•	•	•	•	•	•	•						•	•			•	•								•
improving safety by preventing crashes	•	•	•	•	•	•	•	•						•	•			•	•		•	•	•	•	•		•
Prime and main goal of their implementation is safety	•	•	•	•	•	•	•	•						•	•			•	•		•	•	•			•	•
No need to operate a big traffic control center	•	•	•	•	•	•	•	•					•	•	•		•	•	•		•	•	•				•

Systems Benefit

ITS have not been used for a long time and also lots of ITS application has not been passed their complete implementation period since they used. Also in order to the cost of the evaluation projects and before-after studies, enough data has not been available for an integrated data bank yet, Mitretek System consultant, (2000).

Table 2. Selected systems for locating

CATEGORY	System
Crash prevention and safety	1)Ramp rollover warning
	2) Curve speed warning
	3) Downhill speed warning
	4) Highway-rail crossing system
	5) Pedestrian safety warning
	6) Bicycle warning system
	7) Animal warning system
	8) Intersection collision warning
Road weather management	9) Pavement condition information dissemination
	10) VSL
Roadway operation and maintenance	11) Fixed anti icing system
Traffic management	12) Automatic enforcement
	13) Lane use/closure

As it is mentioned in introduction, base on the first survey results was published and used by the U.S.DOT's JPO in 2003. Rates from 1 to 5 was assigned to each system, These rates equals orderly equals: none, little, medium, high, very high in JPO study; Average of these rating indexes, which are the results of an on line survey, can be observed in Table 3 (column W''_j).

On the other hand, in 2005 U.S.DOT's JPO summarized evaluation experiences and impact assessment of each ITS application area, presenting the result through a rating system ranging from negative impact to substantial positive impacts. This is related to the number of studies that found these impacts. Presented paper has assigned some digits from 1 up to 5 for these rating orderly. It is shown the results in Table 3 in column W'_j. Finally, the overall rating is achieved for each system, by an average between the results of these two columns (W''_j, W'_j), that in the last column of Table 3 has been shown (W_j).

Costs

In this section generally; units of each selected system has been achieved from SIAC Castle Rock Consultants reports .(2002) and (2001), and after that capital and operation and maintenance cost of each unit have been extracted

All of the costs are transformed to equivalent uniform annual cost [EUAC], so it will be capable to compare them together, because of the cost of technology transform to distinct country , from the high and low range of any costs , high range cost is selected and used in the model . The operation and maintenance cost that was presented in annually cost in ITS JPO (2006) is added to capital cost that is converted to EUAC format. Finally, results are achieved like Table 3 for each of thirteen systems.

Table3. Impact rating and total equivalent uniform annual cost of each elected systems for locating

J	System	W'_j	W''_j	$W_j = \frac{W'_j + W'_j}{2}$	Total equivalent uniform annual cost ($1000per year)
1	Ramp rollover warning	3.75	3.625	3.69	17.35
2	Curve speed warning	3.5	3.5	3.5	4.96
3	Downhill speed warning	3.5	3.5	3.5	4.96
4	Highway-rail crossing system	4	3.5	3.75	24.06
5	Pedestrian safety warning	4	4	4	3.28
6	Bicycle warning system	3	3	3	4.89
7	Animal warning system	3	3	3	7.79
8	Intersection collision warning	3.75	3.75	3.75	27.69
9	Pavement condition information dissemination	4	3.5	3.75	13.23
10	VSL	3.158	3.5	3.329	16.28
11	Fixed anti icing system	3.211	3.211	3.211	4.5
12	Automatic enforcement	2.944	4	3.472	17.75
13	Lane use/closure	3	3.5	3.25	13.44

Note : W''_j : rating indexes base on JPO report 2003

W'_j : rating indexes base on JPO report 2005

W_j : overall rating for system j

Model implementation

In this problem, it is assumed that:

- In each location, just one system should be operated.
- Each system is able to locate in some proper location, not in all of locations.
  So, for this subject, it is defined a coefficient as an “installation capability coefficient (K_{ij})”
- In order to lack of exact crashes statistics, average relative frequency is used.

Constraints in this model are:

- Available budget
- Maximum available number of each system

In order to studies that has been done until now and, on the other hand in some sources like "safety Application of ITS in Rural Areas” and “Rural ITS Tool box” from SAIC, 2002 and in addition our opinions for selection procedure of primary locations descriptive characteristics of hot spots for installing systems are suggested for each of thirteen systems in Table 4. It is obvious that, due to every road characteristics and also engineering judgment after road surveys these suggestions could be changed. In this table it is presumed that traditional fixed traffic signs beside the road, have installed in suitable locations.

Table 4. Some suggestions for selection of primary locations for each chosen system

code	System	Suggested criteria
1	Ramp rollover warning	Existence of sharp grade and a curve after that
2	Curve speed warning	Existence of some sharp curve in continues with speed limit sign for them
3	Downhill speed warning	Existence of long and sharp grade and it's yield sign
4	Highway-rail crossing system	Existence of a grade intersection between rail and highway
5	Pedestrian safety warning	Existence of pedestrian crossing sign in residential areas
6	Bicycle warning system	Existence of tunnel and gallery
7	Animal warning system	Existence of animal crossing yield sign
8	Intersection collision warning	Existence of a main intersection
9	Pavement condition information dissemination	Existence of a curve and a bridge or a steep way after that
10	VSL	Existence of constant speed limit sign related to geometric design of highway
11	Fixed anti icing system	Bridges or culvert
12	Automatic enforcement	Existence of high portion of road accident frequency
13	Lane use/closure	Existence of downfall from hillside

Formulation

Formulation procedure, which was mentioned for model planning, in previous sections and optimization problem formation method, is shown in Figure 1.

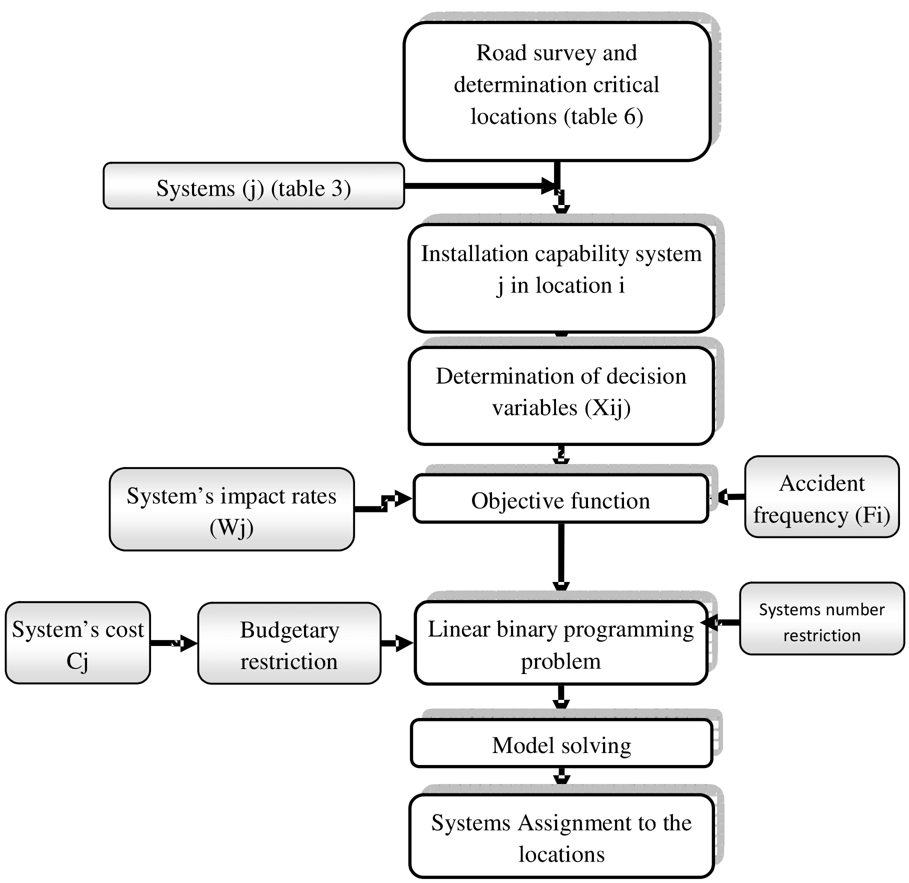

Figure1. Model formation method

The planned problem is an integer linear programming, and also because decision variables in the problem can be 0 or 1 so presented problem will be binary programming. Suggested model presents by using previous data as follow:

Objective function: $max\ Z = \sum_{i=1}^{n}\sum_{j=1}^{m} K_{ij} F_i W_j \cdot X_{ij}$ (1)

s.t.:

Budgetary restriction: $\sum_{i=1}^{n}\sum_{j=1}^{m} C_j X_{ij} \le C$ (2)

Systems number restriction: $\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ij} \le a_j$ (3)

And

Xij is binary

m: Total number of systems that can be installable in the route

n: Number of primary locations for installing systems

$K_{ij}: \begin{cases} 1 & \text{If system j is utilizable in location i} \\ 0 & \textit{if not} \end{cases}$

F_i*:* Accident Frequency during the study period

W_j*:* Impact rate of system j

X_{ij} *:* Decision variable of the problem: $\begin{cases} 1 & \textit{if system j is usable in location i} \\ 0 & \textit{if not} \end{cases}$

C_j*:* Equal annual uniform capital and operation and maintenance cost of system j

C: Total budget that is assigned to target road for improving safety by ITS applications

a_j*:* Number of system j that is available

i: Locations *i*= 1,2,…,n

j: Systems *j*=1,2,…,n

A CASE STUDY

To determine the applicability of the suggested model, the solution algorithm is served to detect an optimal set of location to install chosen systems in 43 km of the Karaj-Chaloos a two lane rural highway. For this purpose, in a survey of this mountainous rural road, needed information (such as geometric characteristics, intersection, bridges and tunnels locations and road slope) were acquired. Spots locations were specified and marked by GPS. Moreover, for choosing the primary installing locations the highway police comments and Table 4 criteria were considered . In conclusion,47 sections were selected as primary locations in the model for installing system, these sections are shown in table 8 .

Usability of system j in location i is shown in Table 5. In the last row of this table, average accident frequency rate during the 3 year (2000-2003) based on highway police information for each location is illustrated.

Table 5 – Primary selected locations for each system and average accident frequency rate for each section

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
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Accident rate	102.8	102.8	102.8	102.8	102.8	102.8	102.8	102.8	84.6	84.6	84.6	84.6	84.6	84.6	84.6	84.6	84.6	84.6	61.4	61.4	61.4	61.4	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	64.6	64.6	64.6	64.6	64.6	101.2	101.2	101.2	101.2	101.2	51.8	51.8	51.8	51.8	31.2	31.2	31.2

For budgetary restriction, it is assumed that, for improving safety by ITS devices, fifty thousands dollar was assigned and for second restriction; maximum number of each system that is wanted to use; is deploying three systems from pedestrian safety system, and three system from bicycle warning system are assumed, and for others there is no number restriction. The model is solvable by manual method, or by each linear programming solver soft wares. Results will be binary numbers 0, 1 that were assigned to decision variables. Model results shows that the best solution is assignment of three curve speed warning systems, three pedestrian safety systems, two downhill speed warning system, one bicycle warning system, and finally one Anti-Icing system (fixed winter maintenance system), that are shown on route plan in Figure 2 in appendix

As it is observed, five types of systems are chosen, and their choosing procedure is related to the costs and benefits of the each system, that were presented in Table 3. In this set of location the sensible factor is major portion of systems that is allocated in some distances like: 0-5, 5-10 and 20-35, where have greater accident frequencies via other sections. Consequently the model behavior is logical, generally.

CONCLUSION

In this paper, due to some factors that contributed to each vehicle's involvement in crash, all ITS applications that might reduce different type of rural crashes, were determined, and then the decision procedure of determining the most effective locations for installing by a linear integer programming were modeled, and also a quantitative index from the last studies were concluded to compare safety benefits of each system and each location is valued by its accident history. Considering to all ITS potential for improving safety in rural roads in a comprehensive process is really helpful. In an experiment design the operating model concluded some controlling points of the model behavior.

By deploying the fine statistics from exact cause of the crashes and use the last different studies, the most effective solutions and better system locating will be available. Separate surveys on install location characteristics and also analyzing effectiveness of each system individually and their calibration can present some more distinctive characteristics of the systems. Study on driver's behavior and their reaction to ITS warning messages are from aspects that determine effectiveness of ITS applications. Moreover a study like this paper could be done on portable intelligent transportation systems in rural areas.

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Figure 2 – chosen locations by solving model and their appearances on Karaj-Chaloos highway plan

Table7. ITS solution on rural road safety (Mccormack and Leg 1999)

Contributing Crash Factors	Rural Safety Issue	% of Vehicles in Rural Crashes in Washington	Possible ITS Solutions
Human	Unsafe Speed or Exceeding Speed Limit	22%	● Speed radar linked to warning sign ● Variable speed limits ● Photo enforcement system
	Inattention or Sleeping	9 %	❍ 🚗Driver monitoring system ❍ 🚗Roadway departure systems
	Judgment Errors	16 %	● Computer-based driver training ● Compute designed roadway signs ❍ 🚗Crash avoidance countermeasure system for older drivers
	Drug or Alcohol	5 %	● 🚗Ignition interlock with breath analyzer
	Other Human Factors	> 0.5 %	Few ITS applications
Road	Weather	23 %	● Area-wide weather warning systems ● Ice sensors linked to warning signs ● Fog, dust or smoke warning systems ● Wind gust warning systems ● Intelligent road markers with weather sensors ● Snow plow ahead warning systems ❍ Snow plow management systems ❍ Advanced technology snow plows ● Automatic anti-icing and de-icing systems
	Wildlife Collisions	5 %	● 🚗Night vision systems ❍ 🚗Roadway obstruction detection
	Work Zone	3 %	● Adaptable variable message signs ● Portable work zone safety systems ● Work zone intrusion warnings
	Other Road Hazards	> 0.1 %	Few ITS Applications
	Pedestrian or Bicycle Involvement	0.7 %	● Self- activated warning signs for roads and tunnels
	Railroad Crossings	> 1 %	● Train conflict sensors and warning signs ❍ In-locomotive "vehicle in crossing" warning systems
	Rural Intersections	28 %	● Approaching vehicle warning sensors and signs
Vehicle	Truck (over 10,000 lb.) Involvement	7 %	● Truck classification detectors and warning signs at hazardous locations ● Automated commercial vehicle inspection and enforcement programs
Post-Crash	Emergency Notification		● New technology call boxes ❍ 🚗In-vehicle mayday systems
	Incomplete or Inaccurate Crash Reports		● Total stationing for crash reporting ● Portable computers in police vehicles ● Crash reporting systems utilizing GPS and GIS software

● = Application feasible currently or in the near future
❍ = Potential future application
🚗 = Application from vehicle manufactures

Table 8- Numbers and distances from the origin of sections and their suitable system

i	Distance from origin	Proper system for installing	i	Distance from origin	Proper system for installing
1	0+400	VSL	25	17+381	Pedestrian safety warning
2	0+750	Automatic enforcement	26	17+393	Automatic enforcement
3	1+480	Pavement condition information dissemination	27	17+510	Intersection collision warning
4	2+105	Curve speed warning	28	17+414	Lane use/closure
5	2+590	Curve speed warning	29	19+580	
6	3+380	Pavement condition information dissemination	30	19+775	Curve speed warning
7	3+720	Pedestrian safety warning	31	22+830	Ramp rollover warning
8	3+870	Curve speed warning	32	23+120	Downhill speed warning
9	5+290	Pedestrian safety warning	33	22+720	Downhill speed warning
10	5+600	Curve speed warning	34	24+600	Bicycle warning system
11	5+750	VSL	35	24+760	Bicycle warning system
12	5+770	Pedestrian safety warning	36	27+000	Automatic enforcement
13	5+985	Curve speed warning	37	27+230	Lane use/closure
14	6+665	VSL	38	27+870	Bicycle warning system
15	8+380	VSL	39	28+635	Bicycle warning system
16	8+453	Fixed anti icing system	40	29+100	Bicycle warning system
17	8+535	Curve speed warning	41	32+540	Bicycle warning system
18	9+590	Lane use/closure	42	33+450	Bicycle warning system
19	11+082	Curve speed warning	43	34+050	Bicycle warning system
20	13+190	VSL	44	34+960	Fixed anti icing system
21	13+250	VSL	45	40+595	Pavement condition information dissemination
22	14+930	Curve speed warning	46	41+480	Intersection collision warning
23	16+970	VSL	47	41+860	Pedestrian safety warning
24	17+027	Pedestrian safety warning			